Broadcast Signal Lab

National Lawyers' Guild
Committee on Democratic Communications

Receiver Evaluation Project

June 30, 1999

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Foreword

This test was commissioned to acquire knowledge that could contribute to discussion of low power FM services. Specifically, the test was intended to develop a data set that shows the relationship between actual interference and the interference ratios prescribed by the FCC. This was accomplished by characterizing the behavior of receivers subjected to potentially interfering signals at varying levels and with different kinds of modulation.

The following persons and entities funded this receiver test project:

National Lawyers Guild Committee on Democratic Communications
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Executive Summary

The National Lawyers' Guild Committee on Democratic Communications commissioned Broadcast Signal Lab, LLP to evaluate ten consumer radios of various types. The radios were grouped in three broad categories, higher priced radios (greater than approximately $150), lower priced radios ($20 to 150), and factory installed car radios. They were tested in a manner that permits comparison of each radio's performance to the FCC-specified ratios for interference from undesired radio signals. The FCC-specified ratios apply to undesired signals that are on the same channel as the desired signal and on channels that are the 1st, 2nd, and 3rd adjacent to the desired signal. Some radios were also tested with a 4th adjacent channel undesired signal.

<u>General Observations</u>

Overall, radio performance tended to relate to the FCC ratios in two ways.

- First, car radios and higher priced radios performed far better than one would predict based on the FCC interference ratios. Substantial signal strengths were required to cause 2nd, 3rd, and 4th adjacent channel interference.

- Second, performance of lower priced radios tended to "straddle" the FCC ratio reference levels.

Of the radios tested for fourth adjacent interference, each exhibited strong similarities between its second, third and fourth adjacent channel performance. Higher priced radios and car radios tolerated fourth adjacent channel signals by a considerable margin above the FCC interference ratio reference levels (for third adjacent channel signals)). While one might expect interference susceptibility to decrease as the adjacency increases from second to third to fourth, the tests did not show this to be the case. A radio could be more susceptible to interference on one of those three adjacencies, but it could as well be from the third or fourth adjacency as the second.

<u>Other Findings</u>

It is difficult to establish a definition of unacceptable interference. The tests demonstrated that even the best receivers showed measurable, often imperceptible, increases in distortion in the presence of extremely low level undesired signals. It is clearly inappropriate to define this measurable degradation as interference. Historically, an absolute amount of noise or distortion is established in a test, somewhat arbitrarily, as indicating unacceptable interference is present, such as a 3% increase in distortion, or a signal to noise ratio of 30 dB. However, actual FM listening conditions are dependent on such variables as reception conditions, baseline radio performance without interference, and the various sounds and effects that interference can create. These variables make it difficult to scientifically derive a universal measure of unacceptable interference.

Executive Summary

The tests revealed a useful behavior common to all radios. It was found that the distortion-and-noise performance of each radio exhibited a "transition zone" where the radio would suddenly fail to receive the desired signal. The transition zones were used to make comparisons between various radios, between various forms of undesired signal modulation, and between interference from various adjacencies.

While the transition zone in the distortion-and-noise tests does not pinpoint the conditions under which a listener will decide a signal is undesirable to listen to, it is the most identifiable characteristic common to the radios in the tests.

Modulation of the Undesired Signal

More aggressive modulation of the undesired signal did not cause a significant increase in interference. This was especially true at the higher adjacencies (2nd, 3rd and 4th).

Less costly radios were more susceptible to modulation-induced interference than more costly radios.

Interference Evaluated by Adjacency

Co-channel and First Adjacent Channel

FCC interference ratios for co-channel and first adjacent channel signals appear to be realistic. Using the "transition zone" described in this report as a reference, the response of all radios tested for co-channel and first adjacent channel interference matched or exceeded the FCC ratio reference level.

Second Adjacent Channel

Higher priced radios tend to withstand second adjacent channel interference better than lower priced ones. Higher priced radios and car radios withstood undesired signal levels higher than the FCC ratio reference levels.

Compared to other adjacencies, radio performance against second adjacent channel undesired signals exhibited the widest variation. The poorest performing radios were susceptible to second adjacent channel undesired signal levels that were as much as 50 dB lower than the levels that affected the best performers.

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Third Adjacent Channel

Third adjacent channel interference was slightly less challenging to most radios than second adjacent interference. Higher priced radios and car radios tended to fare better than lower priced radios.

Fourth Adjacent Channel

Performance of those radios tested against fourth adjacent channel interference was similar to their performance against third adjacent interference.

Second, Third, and Fourth Adjacent Channel Comparison

Higher priced radios and car radios withstood interference from second, third and fourth adjacent signals greater than the FCC ratio reference level.

With higher priced radios and car radios, test levels at second, third and fourth adjacent channel approached or exceeded that which would only occur in the blanketing interference area close to the undesired signal transmitter. Under current blanketing rules, the blanketing area of a ten watt facility in an urban environment might encompass about 67 people (assuming 30,000 people per square mile.) Those people would not necessarily experience any interference. Rather, they would be eligible for a remedy from the new station *if* it were to cause interference.

Frequency separation between the desired and undesired signals is not a strong predictor of interference from second, third and fourth adjacent channel signals. In some cases, radios were more susceptible to interference from a higher adjacency than a lower one.

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Broadcast Signal Lab

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Tab 1

Test Description
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Test Description

Purpose

The purpose of the receiver test is to develop a data set that shows the relationship between actual interference and the interference ratios prescribed by the FCC. This is accomplished by characterizing the behavior of receivers subjected to potentially interfering signals at varying levels and with different kinds of modulation.

Test Setup

<u>Desired Signal</u>

A “desired signal” was created on the test bed and fed directly to the antenna terminals of a receiver. The desired signal’s level was chosen to approximate that typically encountered by a receiver at the protected contour of a station. A 60 dBu contour (1 mV/m at 30 ft elevation) might translate to 316 microvolts on a receiver’s input with a dipole antenna. Accounting for losses closer to the ground, our experiments with received signal levels suggested that 80 to 200 microvolts would be a more likely range.

A McGraw Edison FM alignment generator was set for –54 dBm (50 ohm), or about 300 uV. The output of the generator was coupled to a frequency counter to verify correct frequency. The counter was removed and the signal was connected to an IFR return loss bridge set up as a combiner. This combiner would also receive the interfering signal, and output both to the radio under test.

The desired signal was set at 97.7 MHz, close to the 98 MHz mid-band point frequently used for receiver testing. This frequency is co-channel with a Class A station approximately twenty miles away and fourth adjacent to Boston Class B stations on 98.5 and 96.9 MHz fifteen to twenty miles away. The level of the co-channel signal was so attenuated by the test location and the Faraday cage employed in the test, that it was undetectable on the radios under test. The on-air fourth adjacent signals were detectable by some of the radios under test, but sufficiently low in received level that the radios were unaffected by them, and the test signals were orders of magnitude greater than them.

<u>Signal Coupling</u>

No impedance match was made to translate the 50 ohm source to the nominal 75 ohm input of some receivers. Other radios that had no antenna terminals were directly connected to the source by alligator clips or tack soldering. The RF level of the desired signal was adjusted to obtain two conditions, full quieting and 50 dB quieting, and the desired signal levels were noted. These measurements of performance without an undesired signal present provided informal verification that the test level was appropriate for each radio under test.

To verify correct setting of signal levels and the correct setting of the ratio between the two signals, the output of the combiner was temporarily switched to a Tektronix 2710 spectrum analyzer whenever levels were adjusted. After approximately 7 dB of line and combiner loss, the unmodulated desired signal level appeared on the analyzer at 46 dBuV (200 uV). The output was then switched to the radio under test.

Undesired Signal

The interfering signal, also referred to as the undesired signal, was generated by a Harris Digit Exciter. This device made it possible to introduce undesired signal levels as much as 70 dB greater than the desired signal. The output of the exciter was passed through a General Radio sampling attenuator to a dummy load. The attenuator output was connected to the second input of the combiner. Modulation was removed from both signals. The attenuator was adjusted to obtain an undesired signal level at the selected ratio to the desired signal.

Receiver overload was a potential consequence of the testing. In the cases of 2^{nd}, 3^{rd}, and 4^{th} adjacent channel interference testing, the reference ratio places the undesired signal 40 dB higher than the desired. The test was conducted with undesired signals as much as 30 dB higher than the FCC reference ratio and 70 dB higher than the desired signal. Since the desired signal was set at a nominal 60 dBu value, the undesired signal could be as high as a nominal 130 dBu. FCC blanketing rules apply to individual stations whose levels are greater than 115 dBu. The test plan inherently exercises the radios' response to potential blanketing interference.

The measurement procedure permitted the radios to retain capture of the desired signal for as high an interfering level as possible. The radio under test was tuned to the desired signal while the undesired signal was kept low. The level of the undesired signal was increased progressively. No formal testing was done in the reverse order—that is, allowing capture of the undesired and reducing its level until the desired is captured.

Signal Purity

Both of the signal generators were tested for noise, distortion, occupied bandwidth and spurious emissions, using the spectrum analyzer and the modulation monitor. RF performance was well within the FCC limits and audio performance was more than sufficient to test consumer radios.

Source Material

The undesired signal was modulated with audio from a CD. This CD, created specifically for the test, contained a 1 kHz test tone and a segment of music with percussion. It was played on a Denon player into the analog inputs of a Panasonic DAT machine. The DAT machine was used as an A/D converter to drive the AES/EBU input to the Harris Digit exciter.

The Harris exciter internally generates a stereo signal when commanded by a control input that was attached to a switch on the test bed. Modulation was set to 100% each time the test mode was changed. The music was transmitted in stereo. The tone was input equally on left and right inputs to the exciter and transmitted in both stereo and mono modes.

The desired signal was modulated by a 1 kHz tone generated by the Audio Precision test set. It was transmitted as a stereo left channel-only signal.

Test Facility

Testing was conducted at Broadcast Signal Lab's Medfield Massachusetts facility. A 10 by 12 by 8-foot screen Faraday cage was constructed in a below-grade room. Ambient broadcast signal levels were attenuated approximately 50 dB by the cage. Some of the test devices generated their own low-level RF emissions because of the computer technologies incorporated in their designs. These devices were placed outside the test cage to reduce their influence on the testing.

Test Elements

<u>Interfering Signals</u>

Each receiver was tested for co-, first, second, and third adjacent channel interference. Four receivers were tested for fourth adjacent interference as well. The undesired signal level was established in relation to the FCC ratios for commercial stations:

Co-channel reference	Desired 20 dB above undesired
1st adjacent reference	Desired 6 dB above undesired
2nd and 3rd adjacent	Desired 40 dB below undesired
4th adjacent reference	Not regulated; The tests used 2nd and 3rd adjacent value for comparison

The level of each undesired signal was set to as many as six values per test:

-20 dB	Undesired set 20 dB below FCC interference ratio reference
-10 dB	Undesired set 10 dB below FCC interference ratio reference
0 dB	Undesired set to produce reference interference ratio above
+10	Undesired set 10 dB above FCC interference ratio reference
+20	Undesired set 20 dB above FCC interference ratio reference
+30	Undesired set 30 dB above FCC interference ratio reference

These values appear on the horizontal axes of the graphs presented in this report. In plain terms, the 0 dB position on a graph shows how a radio behaves when subjected to interference equal to the FCC interference ratios for commercial stations. The positive numbers (e.g., +10 dB) show how a radio behaves when subjected to more interference than the FCC ratios. Thus, the negative values (e.g., -20 dB) show how a radio behaves when the interference is less than the FCC ratios allow.

<u>Undesired Signal Modulation</u>

Once an undesired signal level was set and measured, the undesired signal was modulated in five ways:

No modulation
9% Pilot only
Mono tone at 100 % modulation (1 khz tone)
Stereo L=R tone at 100% modulation including 9% pilot
Stereo audio at 100% modulation (unprocessed Steely Dan tune with strong rhythm)

<u>Modulation Check and Test Filter</u>

A QEI modulation monitor was used to verify modulation on both the desired and undesired signals. The composite section of the QEI was used as a buffer amplifier with a 15 kHz low pass filter to remove unwanted 19 kHz energy from some of the radios' outputs. Its de-emphasis circuits were disabled.

<u>Measurement of Desired Signal</u>

With each type of modulation of the undesired signal, two measurements were made on the desired signal. First, the desired signal was measured for left channel noise using only a stereo pilot injected into the desired signal at 9%. The Audio Precision measurement instrument was set for IEC weighting and 100% modulation reference. Second, a 1 kHz tone modulated the desired signal to 50%, including the 9% pilot. This tone was used to perform a total harmonic distortion and noise measurement (THD+N) on the modulated desired signal.

<u>Data Points</u>

Each receiver was tested against co-channel signals and three or four adjacencies at up to six levels of undesired signal with five forms of undesired modulation and two forms of desired signal modulation. These 200 to 250 data points per radio were tabulated, and numerous combinations have been presented in graphs.

To show the point at which complete failure to receive the desired signal occurs, the graphs utilize a special convention. A figure of 100% distortion was entered when the desired signal's tone could no longer be recovered for measurement. A figure of 0 dB signal to noise was entered in the noise measurement data when measurement became impossible or meaningless.

In addition to the noise figures and the distortion and noise figures, other characteristics of the test were noted. If a noise or a distortion and noise reading displayed a wide variation during measurement, the variation was noted. A letter code was added to indicate the nature of the variation. If a noise or a THD+N reading was unobtainable, the cause of the problem was noted as a letter code. This information is in the data table but has not been incorporated in the graphs.

The characteristic codes used are:

C Capture. Radio under test has captured the undesired signal such that a distortion or noise figure measures the performance of the undesired signal.

U Uncapture/Unreadable. Radio under test is producing noisy audio that sounds like both signals are being demodulated equally poorly.

B Beat effect. Cyclical beat causing distortion or noise level to vary with the cycle. The median value is reported and a variation in plus or minus dB or percent is recorded separately on the database.

E Excursion. Non-cyclical variation in indication due to impulses from modulation of undesired signal. The reported value is the quiescent value of the desired signal's noise or distortion. The excursion with interfering impulses is indicated separately in the database as plus-dB or plus-percent over the base value.

M Mute. In response to some undesired signals some radios switch to a mute or noise blanking mode.

Radios Tested

Eleven radios were tested. They are described in a table in the equipment appendix. A stereo desired signal was applied to each radio, regardless of whether it was a mono or stereo radio. Stereo radios were placed in stereo mode. Some stereo radios had stereo modes that include an automatic noise blanking or muting feature. Others had separate muting controls that were disabled for the test. Stereo radios that incorporated high blend or automatic switching to mono, such as the car radios, were tested without regard to the mode they had automatically selected. Stereo radios that required manual switching to mono, noise reduction, or narrow band IF filtering were left in normal wide band modes.

Four of the radios were higher cost component stereo tuners and receivers, two analog and two digitally tuned. Five of the radios were lower cost units (<$120±) that included a clock radio, two boom boxes, an integrated CD changer, cassette, and receiver with separate speakers, and a Walkman. Two were factory installed car radios.

Four radios were tested with fourth adjacent channel undesired signals. The test plan originally did not include such testing. However, as the testing began to show relationships between second and third adjacent signal performance, it became clear that fourth adjacent channel testing would be illuminating. The original plan identifed a band of frequencies that could support a successful test of first, second, and third adjacent signals. In the metropolitan Boston area, with its crowded FM spectrum, reliable fourth adjacent channel testing seemed unlikely. After construction and testing, the Faraday cage was found to provide the attenuation needed to perform reliable tests with the fourth adjacency.

Antenna Coupling

The clock radio and Walkman were disassembled to gain access to antenna points on their circuit boards. The Walkman was particularly difficult to couple signal to and the test bed signal levels had to be increased to achieve useable signal levels. As a result, there was not enough headroom in the desired signal source to test all D/U ratios.

Two additional Walkman-style radios and two additional clock radios were obtained for the test. Upon initial set up the additional walkmen were at least as difficult to test as the original. The two clock radios had nearly identical circuitry to the one tested. To focus on obtaining data on a variety of radios, these radios were not tested.

The boom boxes had telescoping antennas, to the bases of which the RF source was clipped. A circuit ground was obtained through the battery compartments. The integrated and component radios had antenna terminals. The car radios were removed from their vehicles and powered with a 12 volt bench supply.

Audio Sample

Audio was sampled from the tape outputs of the component radios. The boom boxes and Walkman were sampled from their headphone jacks. The speaker terminals of the clock radio, Toyota radio, and integrated system were used. These were adjusted in level to achieve optimal noise and distortion performance. The clock radio was adjusted in audio level for optimum distortion and separately for optimum noise performance. A separate line level output was used on the Ford radio that preceded all tone, volume and balance controls. Some radios had significant 19 kHz components in their outputs that required filtering.

Test Results

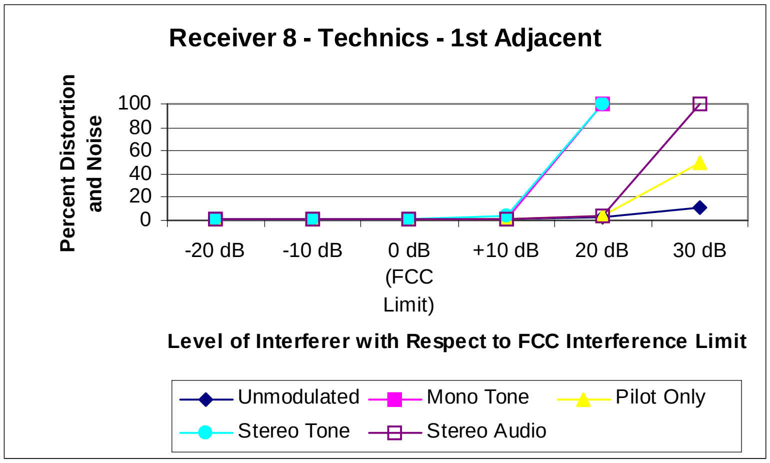
The attached table contains all the data collected during the tests. It is organized first by radio, then by undesired signal (co-channel, 1st adjacent, etc.), then by modulation of the undesired signal. Horizontally the data are presented in increasing level of undesired signal. Variance amounts and codes are presented with measurements to which they apply.

Various graphs were plotted and are submitted with this report.

Radio Performance Graphs by Adjacency of Undesired Signal

Each radio has a separate graph for each undesired signal (co- through 3rd or 4th adjacent). The graphs show THD+N level versus undesired signal level. Each graph has five plots representing the five ways the undesired signal was modulated. In the sample below, a Technics receiver was subjected to a first adjacent undesired signal. The undesired signal was modulated five ways and set at six levels.

Figure 1



Radios Grouped by Class and Adjacency

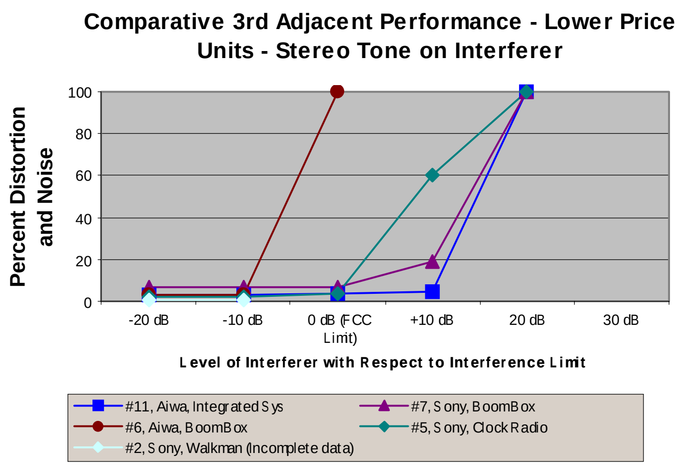
Another set of graphs shows radios grouped in three broad classifications:

1) Higher priced radios: stereo component tuners and receivers;
2) Car radios;
3) Lower priced radios (<~$150): boom boxes, integrated system, clock radio, Walkman.

Each graph shows a class against an undesired signal (e.g. 3rd adjacent). All graphs show performance against stereo tone on the undesired signal.

The sample below shows the lower priced class against third adjacent.

Figure 2

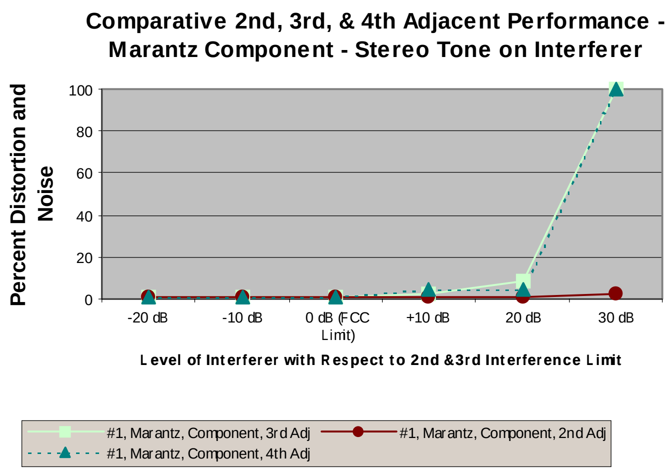


2nd, 3rd and 4th Adjacent Performance for Individual Radios

Some radios were tested against a 4th adjacent undesired signal. Each radio is presented in a separate graph comparing its performance in the presence of 2nd, 3rd, and 4th adjacent undesired signals.

The sample below shows a Marantz receiver subjected to 2nd, 3rd, and 4th adjacent undesired signals.

Figure 3



Graph Limitations

THD+N Values Used in Most Graphs

Most of the graphs presented show THD+N figures (total harmonic distortion plus noise). A 100% value indicates total failure to receive the desired signal. As the undesired signal level increases, THD+N will increase slightly, then more dramatically. The actual point where "interference" occurs is not specifically identifiable.

The intent of showing these "curves" is to give an impression of how each receiver responds to undesired signals. Some might argue that, say, 10% THD+N is the limit of tolerable or intelligible listening. Others might suggest that interference occurs when THD+N begins to show a material increase over the baseline figure, such as an increase of 1 percentage point. Our experience in years of listening and in this test project, is that interference manifests in many forms, some more tolerable to hear than others and perception of interference also depends on the nature of the desired program content. Therefore no absolute THD+N or noise value can be cited as an interference threshold.

The graphs can not resolve this dilemma. However, by showing performance against a steadily increasing undesired signal level, the graphs may illustrate the *range* in which each receiver develops symptoms of interference. This creates an opportunity to compare the ranges of response between receivers.

Linear Scale Hides Subtle Variations in THD+N

To illustrate the transition to total failure to receive the desired signal, a figure of 100% THD+N is used. Because a linear scale is used on the vertical axis of the graphs, variations of a few tenths or one percent THD+N will not be readily apparent on the graphs. However, a mild slope, for instance, from 1% to 1.5% to 2.5% THD+N, is visible and shows how interference may gently increase linearly in some circumstances prior to non-linear response.

Undesired Signal Increased in 10 dB Steps

Ten dB increments in undesired signal level are sufficient to show a radio's performance in comparison to other radios tested. On the "flatter" portions of each curve, the gradual increase in THD+N level and steady decrease in signal to noise ratio are clearly represented. The transition zones between gradual change and total failure are identified between a pair 10 dB undesired signal level increments. This is sufficient resolution to compare groups of receivers.

The 10 dB increments of undesired signal level are not sufficient to make precise conclusions about individual receivers. As the interference response goes non-linear (starts to "take off"), it tends to do so within one, sometimes two, 10 dB increments of undesired signal strength.

Consider for example, Figure 1 above. The radio appears to succumb to tone modulated interference at an undesired signal level 10 dB lower than it does with a stereo audio modulated signal. It would be appropriate to conclude that there is *up to* a 10 dB difference in the radio's performance between tone modulated and stereo audio modulated first adjacent channel signals. However, the range of undesired signal levels describing the radio's transition zone is identified with enough resolution to make comparisons with other radios.

<u>Data Tables</u>

Included in an appendix to this report are tables of measured data. They are organized by radio and undesired adjacency. Each table contains noise data taken from an unmodulated stereo desired signal and THD+N data taken from a 1kHz tone, L=R stereo, 50% modulated desired signal.

When additional characteristics were noted, they were taken as numeric variances and alpha codes. The codes are described above. When a data point is labeled "b" it is a median value. The variance value for a "b" data point represents the plus-or-minus variation in the measured value over a series of measurements.

When a data point is labeled “e” it is a minimum, or quiescent value. The variance value represents a maximum increase in noise (decrease in SNR) or a maximum increase in THD+N observed during bursts of interference from the undesired signal.

The other letter codes are not accompanied by variance data.

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Tab 2

Test Analysis

Receiver Test Analysis
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Receiver Test Analysis

Introduction

This test was commissioned to acquire knowledge that could contribute to discussion of low power FM services. Specifically, the test was intended to develop a data set that shows the relationship between actual interference and the interference ratios prescribed by the FCC. This was accomplished by characterizing the behavior of receivers subjected to potentially interfering signals at varying levels and with different kinds of modulation.

The test plan was created to help answer these questions:

How do today's receivers respond to signals at, above, and below FCC-defined interference ratios?

Under what circumstances, if any, can radios tolerate undesired signals greater than those at FCC ratio reference levels?

What is the effect on receiver performance of different forms of modulation of the desired signal and/or the undesired signal?

Interfering Signal Modulation

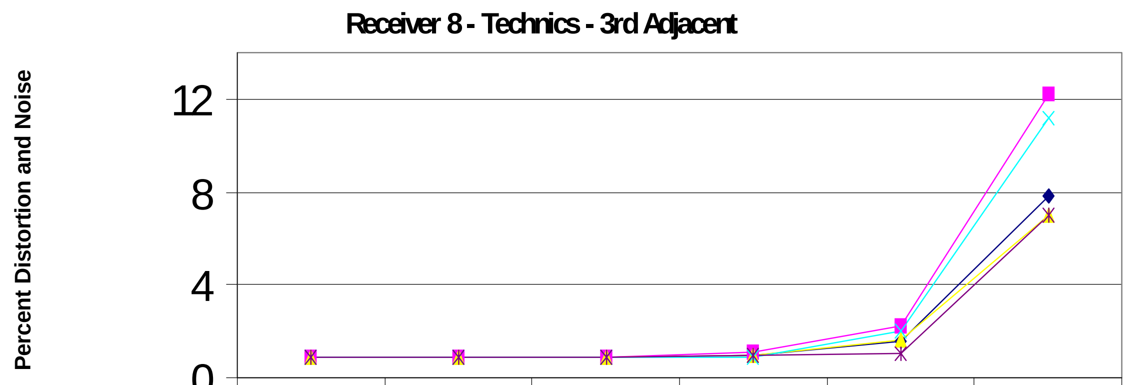
The undesired signal was modulated in five ways: not modulated (carrier only), mono 100% tone modulation, stereo L=R tone at 100% modulation, stereo pilot at 9% modulation, and stereo rock music modulated to 100%. In this section comparisons are made between different forms of modulation of the interfering signal.

<u>Tone Modulation</u>

In general, modulation of the undesired signal with mono and stereo tone was the most challenging to the radios that were tested. See Figure 1 and Figure 2 below. The Technics receiver performance against a third adjacent undesired signal is shown in the figures. Figure 1 contains the receiver's total harmonic distortion plus noise (THD+N) performance, while Figure 2 contains signal to noise performance referenced to 100% modulation.

In most cases, the mono tone and stereo tone modulation can be seen causing slightly greater degradation to the measured performance than the other forms of modulation on the undesired signal. An exception to this generalization is seen in the noise performance of the Technics receiver at FCC+10 dB undesired signal level. Here, the tone-modulated interference is not as severe as interference from other forms of modulation. However, the overall tendency of this and other receivers was to be more susceptible to the tone-modulated undesired signal.

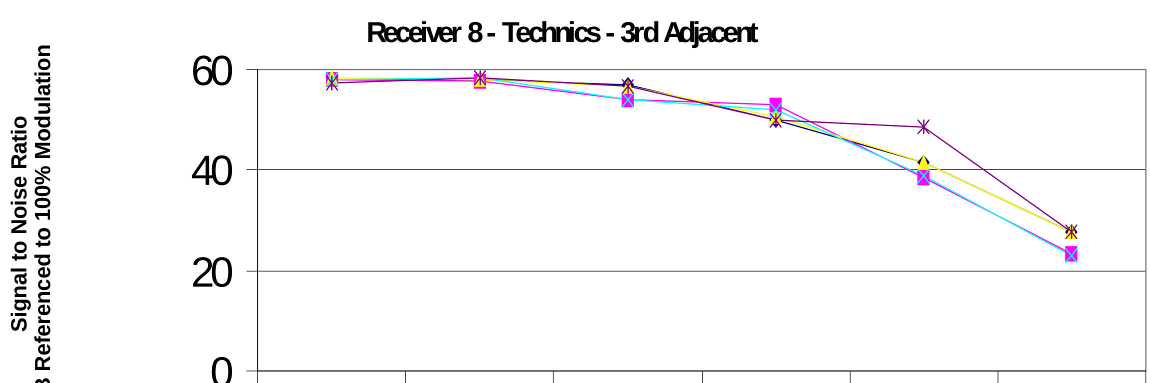
Figure 1: THD+N Performance Example



	-20 dB	-10 dB	0 dB (FCC Limit)	+10 dB	20 dB	30 dB
Unmodulated	0.87	0.87	0.87	1	1.6	7.8
Mono Tone	0.87	0.87	0.89	1.1	2.2	12.2
Pilot Only	0.87	0.87	0.88	0.95	1.65	7
Stereo Tone	0.87	0.87	0.89	0.93	2	11.2
Stereo Audio	0.87	0.87	0.88	1	1.03	7

Level of Interferer with Respect to FCC Interference Limit

Figure 2: Noise Performance Example

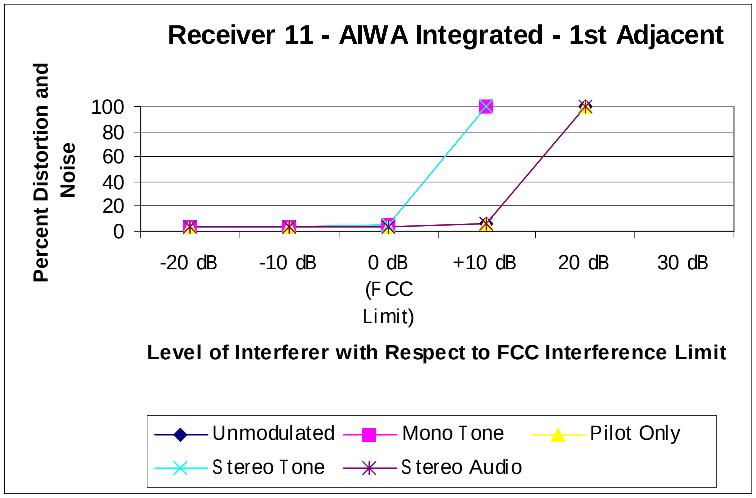


	-20 dB	-10 dB	0 dB (FCC Limit)	+10 dB	20 dB	30 dB
Unmodulated	58	58	57	50	41.5	27.8
Mono Tone	58	57.7	54	53	38.3	23.3
Pilot Only	58.3	58	56.5	50.7	41.3	27.5
Stereo Tone	58	58.3	54	51.8	38.7	23
Stereo Audio	57.4	58.2	56.5	50	48.5	27.5

Level of Interferer with Respect to FCC Interference Limit

This tendency of receivers to perform more poorly when the undesired signal is tone modulated leads some receivers to more rapid failure. Figure 3 illustrates how some receivers fail with lower levels of tone modulated interference.

Figure 3: Severe Effect of Tone Modulation on Undesired Signal
(Stereo tone and mono tone performance follow the rise from 0 dB, the others rise from +10 dB)



Co-channel with Tone

In general, noise and distortion increased more rapidly with tone on the undesired signal, as the signal level is increased, than with other modulation. However, the point at which a radio failed with co-channel signals was about the same, regardless of modulation type.

First Adjacent with Tone

Radios subjected to first adjacent undesired signals were more dependent on the modulation of the interferer than radios faced with co-channel signals. The clock radio and Walkman each tended to fail at one interfering level regardless of modulation. The rest of the radios tended to fail at lower undesired signal levels when the undesired signal was modulated with tone.

Second Adjacent with Tone

The effect of tone modulation of the undesired signal on a second adjacent channel was less divergent than on a first adjacent channel. Tone modulation caused slightly more noise and THD+N, as in the previous cases, but receiver failure was not as dependent on the modulation type. Only the Technics receiver and the Aiwa boom box succumbed to tone modulated interference before other types of modulation.

Third Adjacent with Tone

On third adjacent channel interference, tone modulation was generally not a factor. Most radios tended to be slightly noisier with tone modulation placed on the undesired signal than with other types of modulation. Of the radios that succumbed completely to tone modulated third adjacent channel interference, most did so at the same signal levels as with other forms of modulation. Only the Aiwa boom box failed with tone before it failed with other forms of modulation.

Fourth Adjacent with Tone

Of the four radios tested for fourth adjacent channel interference, tone was no more a factor than were other forms of modulation on the interferer. Most data points show the tone interference as nearly identical to interference from other modulation forms. Only the Aiwa boom box showed a slight increase in tone-related noise before failing.

<u>Program Audio and Pilot Modulation</u>

Transitory and cyclical interference effects were noted under some conditions during the test. These are ascribed to bursts of noise from program modulation (marked “e” in the data) and frequency beating from the undesired pilot and other steady frequencies either transmitted or generated in the receiver (marked “b” in the data).

When these effects occurred, they were mostly in co- and first-adjacent channel situations. Those that occurred in 2nd, 3rd, or 4th adjacent channel situations took place under special circumstances. In some such circumstances the desired signal was affected when it and the interferering signal were modulated only by their stereo pilots. This would be the result of a peculiar combination of factors: a) the particular radio, b) lack of audio on both signals, c) pilot frequencies or other internal frequencies whose difference can produce perceptible beats (~1 Hz in this case), and d) desired-to-undesired signal ratios that create optimal conditions for two frequencies to beat. When audio was added to the desired signal, these effects were no longer apparent.

Similarly, bursty noise effects were noted on some receivers when the interferer was audio modulated and the desired signal had no audio. The percussion of the music on the undesired signal could be measured as bursts of noise on the unmodulated desired signal. When audio was added to the desired signal, the THD+N figures were not materially affected by burst effects.

Other effects were noted in the form of beats or program modulation bursts that occurred in the presence of already-elevated noise and THD+N levels.

In total, these transitory and cyclical events observed on 2nd, 3rd, and 4th adjacent channel interferers number only 19 out of hundreds of data points. They are about evenly split above and below the FCC reference ratio, depending on the radio.

Modulation of Desired Signal

The desired signal was evaluated in the presence of the undesired signal in two ways. With only stereo pilot present with no other modulation, an IEC weighted noise measurement was taken on the left audio channel. The data are reported in dB with respect to 100% modulation.

The desired signal was also modulated in stereo with a 1kHz tone with a 50% total modulation level. The left audio channel was measured for total harmonic distortion plus noise (THD+N). The data are reported in percent THD+N referenced to the amplitude of the received 1 kHz tone.

As described in the previous section, some modes of interference were more noticeable in the absence of audio on the desired signal.

<u>Rate of Change in Noise and THD+N Data</u>

The signal to noise ratio data and THD+N data have other differences in characteristics. The signal to noise data tended to steadily decrease with increasing undesired signal. A radio's noise figures would degrade by 20 to 30 dB over several measurements until the radio failed to reproduce the desired signal. The only radios fully exempt from this trend under all adjacencies were the car radios. They tended to maintain steady or improved noise figures as the undesired signal increased. Only when the failure point was imminent did the car radios show major noise problems.

In contrast to the steady increase in noise with increasing interference, the THD+N data tended to show only a mild increase as the undesired signal was boosted. When the radio was close to failure, THD+N would begin to rise precipitously prior to reception failure. For example, the Marantz receiver subjected to a second adjacent channel undesired signal showed a steady decrease in signal to noise ratio, going from 57 dB to 29 dB over fifty dB of change in undesired signal level. In contrast, its THD+N performance under the same circumstances remained fairly steady at about 0.7% until the highest 20 dB of increase in undesired signal.

Table 1
Marantz Noise vs THD+N Performance
Second Adjacent Undesired Signal, Tone Modulated

Undesired Signal Level with Respect to FCC Ratio, dB	-20	-10	0 (FCC Ratio)	+10	+20	+30
Signal to Noise	57 dB	57 dB	54 dB	48 dB	38 dB	29 dB
%THD+N	.67	.69	.69	.73	.97	2.0
THD+N as dB*	50.5	50.2	50.2	49.7	47.3	41.0

*Note that the THD+N figures in percent are referenced to 50% total modulation, including pilot, with a 1 kHz L=R tone. Converted to dB, they were adjusted to approximate equivalent signal to noise figures by adding 7 dB.

While Table 1 shows only a single example of the difference between the two measurement methods, it illustrates the tendency well. Noise performance steadily degrades while THD+N performance barely changes until later in the test sequence. Some receivers such as the Denon NAB tuner and the car radios, showed less of the tendency.

<u>Comparison of Level of Noise with Level of THD+N</u>

At lower levels of undesired signal, the signal to noise figures are better than the equivalent signal to noise figures derived from the THD+N values. This is consistent with the fact that distortion products may exceed the baseline noise level of the receiver.

As the undesired signal level is increased, one might expect noise to increase until it becomes a material component of the THD+N figure. At this point the THD+N figures could be expected to increase as the noise figures increase. However, at higher levels of undesired signal, the THD+N values, when converted to equivalent signal to noise figures, are not as poor as the corresponding signal to noise figures.

This tendency of the noise figures to degrade more rapidly than the corresponding THD+N figures may indicate a fundamental difference between measuring a modulated and an unmodulated desired signal. The question arises, which measurement is more indicative of interference?

<u>Identifying a Threshold on which to Compare Interference Resistance of Radios</u>

With a steady decline in simple noise performance occurring with increasing undesired signal, there is no threshold at which to point. Purists might argue that any perceptible increase in noise is interference. However, the receiver performance data show that all receivers produce *some* measurable increase in noise at undesired signal levels below FCC ratio reference levels. Therefore interference, as determined by a noise measurement, must be defined subjectively. Variables such as listener tolerance, types of modulation of the desired and undesired signals, and the nature of the desired program content would likely prevent selection of a specific noise figure as a reliable interference threshold.

Similarly, THD+N performance could be set only arbitrarily at some threshold to define interference. Clearly, when distortion and noise are high enough most listeners will tune out of most programming. However, as described in an earlier section, the manifestations of interference—noise, beats, impulses, muting, etc.—influence the tolerability of an affected signal in ways that would be difficult to quantify.

The only clear characteristic on which to compare receivers is their tendency to make a sharp transition from a gradual change in THD+N to a rapid change. This transition occurs in the zone on the THD+N curves represented by the "knee of the curve." Our analysis will make reference to this as the "transition zone."

Radio Performance by Adjacency

The descriptions of the effects of undesired signals are grouped by adjacency, then by radio type. The level of undesired signal will be described in the form "FCC+xx dB." An undesired signal level of FCC+10 dB is ten dB higher than the FCC ratio reference level for the adjacency under consideration.

In some cases, the type of undesired modulation affected a radio's performance, as discussed in an earlier section. In the most extreme circumstances, tone modulation would provoke a radio to enter the transition zone at a lower undesired signal level. The ranges of transition described below include the variations of performance due to different undesired signal modulation types.

Co-channel Undesired Signal

In general, the radios began to degrade significantly or fail when the undesired signals were between the FCC ratio reference level and FCC+10 dB.

1st Adjacent Channel Undesired Signal

Higher Priced Radios

Three of the four higher priced radios exhibited THD+N transition zones with undesired signal levels between ten and twenty dB above the FCC ratio reference level. The other higher priced radio, the Marantz, entered the transition zone ten dB sooner than the others in this category. It entered its transition zone just above the FCC ratio reference level.

Lower Priced Radios

The Walkman was in the transition zone at the FCC interference ratio for first adjacent channel signals. The Aiwa integrated system and the Sony boom box tolerated slightly higher undesired signal levels, entering their transition zones between the FCC ratio reference level and FCC+10 dB. The Aiwa boom box tolerated an undesired signal at FCC+10 dB before entering its transition zone. The Sony clock radio showed only the slightest signs of transition with the undesired signal twenty dB above the FCC ratio reference level.

Car Radios

The Ford and Matsushita radios appeared on the verge of the transition zone with the undesired signal at FCC+20 dB. At FCC+30 dB, the Ford failed under tone modulation but was still succeeding against other modulation of the undesired signal. The Matsushita was seriously affected by tone modulation at FCC+30 dB, yet it remained relatively undisturbed by other modulation types on the undesired signal.

1st Adjacent Channel Summary

Overall, the radios tested responded to first adjacent channel interference by meeting or exceeding the performance expected by the FCC interference ratio for first adjacent signals. That ratio is 6 dB, desired-to-undesired signal. Of the radios tested with first adjacent channel undesired signals, car radios were the most tolerant of these signals.

<u>2nd Adjacent Channel Undesired Signal</u>

Higher Priced Radios

The higher priced radios performed at least ten dB better than the FCC interference ratio for commercial second adjacent channel signals. In order of declining performance: the Marantz exhibited no transition zone up to the highest level of undesired signal, FCC+30dB. The Denon and NAD tuners entered transition to failure above the FCC+20 dB undesired signal level. The Technics entered transition for tone-modulated undesired signals above FCC+10 dB, and for other types of undesired signal modulation above FCC+20 dB.

Lower Priced Radios

The Aiwa integrated system performed best of the lower priced radios, making its transition between FCC+10 dB and FCC+20 dB. The Sony boom box showed signs of transition at the FCC ratio reference level while the Sony clock radio performed well at the FCC ratio reference level. Both radios completely failed at FCC+10 dB. With limited data points on the Sony Walkman, there is still an indication that the radio was in the transition zone at FCC-10 dB. The Aiwa boom box also did not meet the FCC ratio reference level for second adjacent channel signals. It failed with tone-modulated undesired signal between FCC-20 and FCC-10 dB. Against other modulation types, the Aiwa boom box entered transition between FCC-10 dB and the FCC ratio reference level.

Car Radios
The car radios entered the transition zone above the FCC+20 dB undesired signal level.

2nd Adjacent Channel Summary

The higher priced radios and car radios that were tested tolerated undesired signal levels greater than the FCC ratio reference level. Most of the lower priced radios that were tested succumbed to lower levels of undesired signal, at or below the FCC ratio reference level. Second adjacent channel interference performance appears to be dependent on receiver design factors, including a possible relationship to receiver cost.

3rd Adjacent Channel Undesired Signal

Higher Priced Radios

All the higher priced radios tested entered the transition zone well above the FCC ratio reference level, at undesired levels between FCC+20 and FCC+30 dB. At the FCC+30 undesired signal level, the Marantz and the Denon were in complete failure with all forms of undesired modulation. The Technics and the NAD exhibited elevated THD+N at FCC+30 dB, but had not totally failed.

Lower Priced Radios

Three of the lower priced radios entered their transition zones at or above the FCC ratio reference level. The Aiwa integrated receiver was the best performing receiver in this category with a transition zone beginning above FCC+10 dB. Only the Aiwa boom box was shown to enter its transition zone below the FCC ratio reference level, above FCC-10 dB. The Sony Walkman had limited data collected (see Test Description section for more information). Because it showed no transition tendencies at FCC-10 dB, its performance was at least as good as the poorest performer.

Car Radios

Both car radios entered the transition zone above the FCC+20 dB undesired signal level with all forms of modulation.

3rd Adjacent Channel Summary

Radios mostly withstood third adjacent channel undesired signals at the FCC ratio reference level. Higher priced radios and car radios performed better than the FCC ratio reference level and better than the lower priced radios. The lower priced radios performed better with undesired signals on a third adjacent channel than on a second adjacent channel.

4th Adjacent Undesired Signal

Four radios were tested against a fourth adjacent channel undesired signal, the Walkman, Aiwa integrated system, Marantz receiver and Denon NAB tuner.

Denon NAB Tuner

The Denon appeared to be entering transition at FCC+20 dB. This is nearly identical to its second and third adjacent undesired signal performance.

Marantz Component Receiver

The Marantz began to degrade at a lower undesired level than the Denon. However its transition zone appeared to begin in earnest at the FCC+20 dB level as well. Its fourth and third adjacent channel performance were comparable, but poorer than its second adjacent channel performance.

Aiwa Integrated System

The Aiwa integrated system appeared to be in its transition zone by the time the undesired level reached FCC+20 dB. Like its second and third adjacent undesired signal performance, the Aiwa integrated system entered its transition zone at some point after the FCC+10 dB undesired signal level. The radio's fourth adjacent performance exhibits a less steep transition between FCC+10 and FCC+20 dB, suggesting that it tolerates fourth adjacent channel signals slightly better than second and third.

Sony Walkman

Oddly, the Walkman behaved best with third adjacent, second best with second adjacent, and worst with fourth adjacent channel signals. While testing was done only at FCC-20 and FCC-10 dB for technical reasons, the trends are clear. At FCC-10 dB the Walkman was in its transition zone with the fourth adjacent channel undesired signal, and arguably with the second adjacent channel undesired signal. The Walkman appeared unaffected by a third adjacent channel signal at FCC-10 dB.

4th Adjacent Channel Summary

None of the four radios tested with a fourth adjacent channel undesired signal were immune to it. There was a clear association between the priced ranges of the radios and their performance against fourth adjacent signals. The FCC interference ratio for commercial second and third adjacent channel signals was used as a reference for the fourth adjacent signal tests. Higher priced radios tended to succumb to a strong fourth adjacent signal when it became much greater than the FCC reference level. The cheaper radios were susceptible to undesired signal levels less than or equal to the FCC reference level.

A comparison of second, third, and fourth adjacent channel performance was made for each of the four radios tested with a fourth adjacent undesired signal. The comparisons are included in the graphs. The graphs illustrate how each radio's fourth adjacent channel signal performance is comparable to its second and third adjacent signal performance. Between the choices of second, third, and fourth adjacent undesired signals for a given radio under test, one cannot readily predict which will least affect the radio. In one case, second adjacent performance was best of the three undesired signals. In another case, third adjacent performance was best. In a third case, fourth adjacent performance was best. The remaining case presented nearly identical performance regardless of the adjacency.

Conclusions

Unmodulated vs Modulated Desired Signal

THD+N performance may present a more realistic assessment of receiver behavior than noise performance. Noise performance measurements indicate the effect of an undesired signal on a radio receiving a desired signal that has no modulation but stereo pilot. THD+N measurements indicate how a radio behaves under the same interference conditions when the desired signal is modulated. The modulated desired signals showed less degradation up to the transition zone than their unmodulated stereo counterparts.

THD+N measurements show a clear “transition zone” with which radios may more readily be compared. Noise performance tended to show a more continuous decline in quality compared to the THD+N performance. THD+N performance would change slightly until a transition to failure occurred.

Without proper subjective listening tests, it would be arbitrary to select a specific noise figure as the definition of “interference.” While the transition zone in the THD+N test does not pinpoint the conditions under which a listener will decide a signal is undesirable to listen to, it is the most identifiable characteristic common to the radios in the tests.

Modulation of the Undesired Signal

Radio performance was somewhat dependent on the type of modulation on the undesired signal. In general, undesired signals modulated with 100% mono tone and 100% L+R tone with pilot were the most challenging to the radios under test.

The difference between the effects of tone modulation and the effects of other forms of modulation of the undesired signal was most pronounced on first adjacent channel.

Less costly radios were more susceptible to interference than more costly radios. A radio’s susceptibility to interference was most dependent on the level of the undesired signal and less dependent upon the type of modulation on the undesired signal.

The effect of tone modulation on the undesired signal on some radios is clear and repeatable, but not material. When tone modulation of the undesired signal was a factor in a radio’s performance, the noise and THD+N figures would increase at a slightly higher rate than with other forms of undesired signal modulation. When the THD+N transition zone was affected by different forms of undesired modulation, the variation of undesired signal levels was no greater than 10 dB.

Interference Evaluated by Adjacency

Co-channel and First Adjacent Channel

FCC interference ratios for co-channel and first adjacent channel signals appear to be realistic. Using the "transition zone" described in this report as a reference, the response of all radios tested for co-channel and first adjacent channel interference matched or exceeded the FCC ratio reference level.

The radios entered their transition zones in a relatively narrow range of undesired signal levels. The poorest performing radios were susceptible to undesired signal levels that were 20 to 30 dB less than the levels that affected the best performers.

Second Adjacent Channel

Higher priced radios tend to withstand second adjacent channel interference better than lower priced ones. Higher priced radios and car radios withstood undesired signal levels higher than the FCC ratio reference levels.

Compared to other adjacencies, radio performance against second adjacent channel undesired signals exhibited the widest variation. The poorest performing radios were susceptible to second adjacent channel undesired signal levels that were as much as 50 dB lower than the levels that affected the best performers.

Third Adjacent Channel

Third adjacent channel interference was slightly less challenging to most radios than second adjacent interference. Higher priced radios and car radios tended to fare better than lower priced radios.

Fourth Adjacent Channel

Performance of the radios tested against fourth adjacent channel interference was similar to their performance against third adjacent interference.

Second, Third, and Fourth Adjacent Channel Comparison

Higher priced radios and car radios withstood interference from second, third and fourth adjacent signals that were higher than the FCC ratio reference level.

With higher priced radios and car radios, test levels at second, third and fourth adjacent channel approached or exceeded that which is considered "blanketing" interference.

Frequency separation between the desired and undesired signals is not a strong predictor of interference from second, third and fourth adjacent channel signals. In some cases, radios were more susceptible to interference from a higher adjacency than a lower one.

General Observations

Overall, radio performance tended to relate to the FCC ratios in two ways. First, car radios and higher priced radios performed far better than one would predict based on the FCC interference ratios. Second, performance of lower priced radios tended to "straddle" the FCC ratio reference levels. The performance of the lower priced radios was more dependent on type of modulation of the undesired signal, type of radio, and adjacency under test.

Of the radios tested for fourth adjacent interference, each exhibited strong similarities between its second, third and fourth adjacent channel performance. Higher priced radios and car radios tolerated these signals by a considerable margin above the FCC interference ratio reference levels. While one might expect interference susceptibility to decrease as the adjacency increases from second to third to fourth, the tests did not show this to be the case. A radio might be more susceptible to interference on one of those three adjacencies, but it could as well be from the third or fourth adjacency as the second.

♦

Broadcast Signal Lab

Tab A

Appendix A

Blanketing Interference

Blanketing Interference

Definition of Blanketing

To date, we have not identified a well-sourced definition of blanketing interference, other than the technical criteria discussed below. In 47 CFR § 73.318, the FCC defines a *blanketing area*, described below, in which blanketing interference may occur. An *ad hoc* definition of blanketing interference describes it as a form of interference caused by the presence of an overwhelmingly strong signal that suppresses or severely hampers a receiver's ability to receive other signals. It may be manifest as the monopolizing, desensitizing or total disabling of the receiver. Blanketing interference may include adjacent channel interference when such occurs in the blanketing area, but it is capable of interfering with the reception of any desired signal regardless of channel adjacency to that signal.

Blanketing Areas for LPFM Stations

The FCC, in 47 CFR § 73.318, defines FM blanketed area radius as the calculated 115 dBu field intensity contour without regard to antenna height or vertical radiation pattern. The formula given is

$$\mathbf{D\ (in\ km) = 0.394\sqrt{P}\quad or\quad D\ (in\ miles) = 0.245\sqrt{P}}$$

where P is the maximum effective radiated power, in kilowatts, of the maximum radiation lobe. This formula derives from the established relationship of radiated power, distance and field strength in free space. For convenience at lower power levels it may be restated as

$$\mathbf{D\ (in\ meters) = 12.47\sqrt{P}\quad or\quad D\ (in\ feet) = 40.92\sqrt{P}}$$

where P is measured in watts.

The calculated blanketing area radii for several power levels ranging from one watt to one kilowatt are tabulated below.

Table 1. Effective radiated power versus blanketing area radius

ERP watts	blanketing area radius meters (feet)
1,000	394 (1294)
500	279 (915)
100	125 (409)
50	88 (289)
10	39 (129)
2	18 (58)
1	12 (41)

To gain some notion of how many individuals might be in the blanketing area of an LPFM station located in a densely populated area, let us assume a population density of 30,000 per square mile, a figure not unusual for urban areas. Further assume homogeneous population distribution, keeping in mind that departures from homogeneity will affect the accuracy of predictions increasingly as power and area diminish. Based on these assumptions, we obtain the results in the next table.

Table 2. Effective radiated power versus population within blanketing area

ERP watts	estimated number of persons within blanketing area
1,000	5,700
100	570
10	57
1	6

Blanketing in the Test Procedure

The test procedure was conducted in reference to the FCC interference protection ratios for commercial FM stations. At second and third adjacent channels the undesired signal level is permitted to be 40 dB greater than the theoretical desired signal level. At the 60 dBu protected contour of many stations, the undesired second and third adjacent signals would be permitted to be 60 dBu + 40 dB = 100 dBu.

Increasing the level of the undesired test signal on the test bed results in signal levels that approach and surpass the 115 dBu value that the FCC uses to define blanketing area. (On second, third and fourth adjacent channels this level is approximately between the FCC+10 and +20 test levels). Each receiver that was tested exhibited its own characteristic response to increasing levels of undesired signal on the adjacencies. No clear pattern emerged that could be associated with the 115 dBu blanketing area figure established by the FCC.

The FCC figure of 115 dBu is used to describe a geographic area within which a radio broadcaster has certain responsibilities regarding blanketing interference. Therefore, the 115 dBu figure is not necessarily a blanketing interference threshold for all radios. Receiver performance confirms this observation.

Implications to Blanketing Interference Analysis

In Table 2 above, rule of thumb figures are given for population within FCC blanketing areas for various transmitted power levels. The population affected by blanketing *interference* can be expected to be less than the population within the blanketing *area*. This conclusion is based on two factors. Antenna height and vertical pattern are not considered in defining the blanketing area, so actual signal levels will typically be lower than 115 dBu. Second, many of the radios in the test performed successfully with undesired signals at and above the equivalent 115 dBu level. Thus the blanketing area is a very conservative construct intended to assure a thorough response to blanketing interference concerns near a transmitter. Assuming homogeneous population distribution, the population figures presented in Table 2 therefore inherently overestimate potentially affected population.

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Tab B

Appendix B

Graphs:

Comparison of THD+N Performance

--By Radio Type and Adjacency

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Tab C

Appendix C

Graphs:

Comparison of Radio Performance against 2nd, 3rd and 4th Adjacencies

--By Radio

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Tab D

Appendix D

Graphs:

Comparison of THD+N Performance against Modulation Types

--By Radio and Adjacency

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Comparison of THD+N Performance against Modulation Types

--By Radio and Adjacency

Higher Price Receivers

#1 Marantz
#4 Denon
#8 Technics
#9 NAD

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Comparison of THD+N Performance against Modulation Types

--By Radio and Adjacency

Car Radios

#3 Toyota/Matsushita
#10 Ford

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Comparison of THD+N Performance against Modulation Types

--By Radio and Adjacency

Lower Price Radios

- #2 Sony Walkman
- #5 Sony Clock
- #6 Aiwa Boom Box
- # 7 Sony Boom Box
- #11 Aiwa Integrated System

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Tab E

Appendix E

Graphs:

Comparison of Radio Noise Performance

--By Radio Type and Adjacency

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Tab F

Appendix F

Test Bed Diagram and Equipment List

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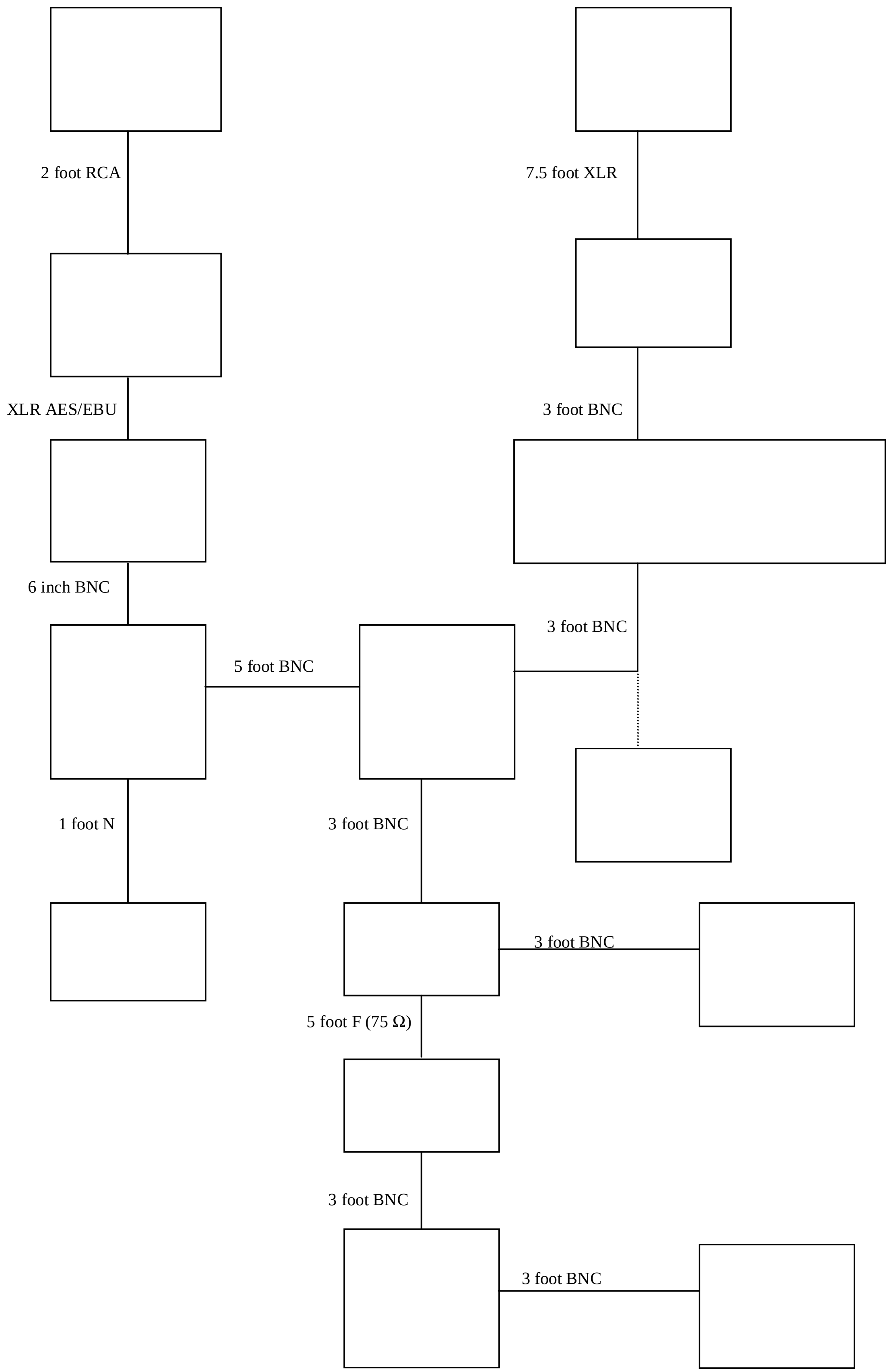
System Block Diagram



Broadcast Signal Lab

Equipment List

Test Equipment	Provided By
Audio Precision Portable One Plus Test Set	Frost Broadcast Associates
Dorrough 80-B Stereo Generator	WJMN, Boston
McGraw-Edison 189 F.M. Alignment Generator	
Denon DCM-350 Compact Disc Player	
Panasonic SV-3900 Digital Audio Tape Machine	
Harris Digit CD Digital Exciter	Harris Communications
Bird 50 watt Dummy Load	
General Radio GR874 Adjustable Attenuator	
IFR AC4101 Return Loss Bridge	
OPTOelectronics 8013-S Frequency Counter	
QEI 691 F.M. Modulation Monitor	
Tektronix 2710 Spectrum Analyzer	

Radios Tested

#	Tested Radio	Year	Type	Tuning
1	Marantz SR2000	198x	Component Receiver	Analog
2	Sony Sports WMSXF 30	1996	Walkman	Analog
3	Toyota Matsushita	1997	Car Stereo	Digital
4	Denon TU-680 NAB	199x	"NAB" Tuner	Digital
5	Sony Clock Radio	1996	Mono Clock Radio	Analog
6	Aiwa	1994	Boombox	Analog
7	Sony CFD 370	1998	Boombox	Digital
8	Technics SA-80	198x	Component Receiver	Analog
9	NAD 412	199x	Tuner	Analog
10	Ford Car Stereo	1995	Car Stereo	Digital
11	Aiwa	1994	Integrated System	Digital

NAB Tuner provided by Loud and Clean Broadcast Science

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Tab G

Appendix G

Data Tables